AMTC
Low Cost Manufacturing of Composite Cryotanks

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Integrated Systems

2nd Generation RLV Airframe Risk Reduction

Cryotank Manufacturing

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Objectives

- Develop and Validate Manufacturing Processes and Technology for Fabrication of Large Scale Cryogenic Tanks
- Establish Scale-Up and Facilitization Plan for Full Scale Cryotanks

- Develop Non-Autoclave Composite Manufacturing Processes
- Fabricate Subscale Tank Joints for Element Tests
- Perform Manufacturing Risk Reduction Trials for Subscale Tank
- Develop Full Scale Tank Manufacturing Concepts

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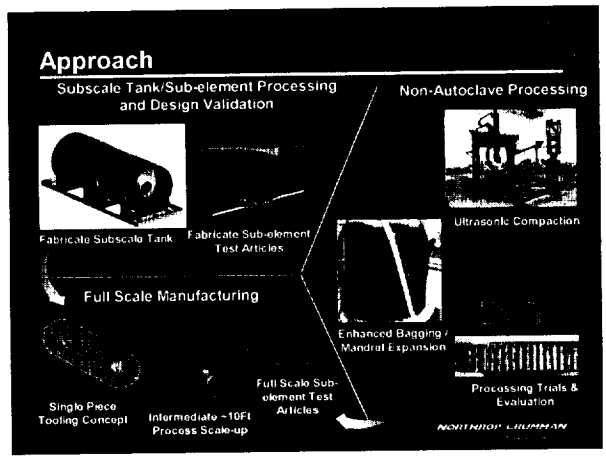
Approach



Non-Autoclave Cure Processes

Ultrasonic Compaction

- UTL Debulked Test Panels Exhibit Autoclave Equivalent Properties and Performance
- Debulk to Net Thickness Eliminates Need For High Pressure During Cure
- Selectively Advances Resin For Increased Material Out-time Prior to Cure
- In-Situ Debulking Permits Thick Section Part Build Ups Without Ply Distortion
- UTL Demonstrated on Other Programs (With Autoclave)

Enhanced Processing

- Evaluate Other Methods Used in Industry
  - Mandrel Expansion
  - Shrink Tapes
  - Double Bagging
  - New Non Autoclave Matls
  - Processes Used for Large Repairs (On Vehicle)
  - Improved Debulking
  - CAI Net Thickness Lay-up Materials

VARTM

- Opportunity to Integrate Features and Details
- Make Large Integrated Structures
- Single Injection Process Minimizes Out-Time Issues
- Better Suited to Monolithic Structures
- Requires Development of Filament Wound Preform Technology

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Non-Autoclave Evaluation Factors

- **Compatibility With Design**
- **Ability to be Scaled Up**
- **Maturity of Materials**
- **Laminate Quality (Compared to Autoclave Baseline)**
  - Cured Laminate Thickness / Thickness Variations
  - Defects and Other Anomalies (Laminate Porosity, Bridging / Resin Starved Conditions, Unbonds/ Entrapped Air and Voids
  - Laminate Anomalies (Mark-off From Processing, Fiber Wrinkling / Waviness, Fiber Volume / Resin Volume Variations)
  - C-Scan
- **Mechanical Properties**

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VARTM Evaluation

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VARTM Evaluation

Materials Maturity

- Unidirectional Preforms Need Significant Development
  - Uni-Fabrics Only Used in Experimental Environments and Have Minimal Process and Mechanical Data Available
  - Filament Wound Tow Preform Concept Requires Development of Compatible Sizing and Method for Integration of Doublers
- Structural Foam Cores Not Mature. Do Not Have Equivalent Strength /Density Ratios to Honeycomb
- Must Develop Weight Effective Method for Scaling/Bonding to use Honeycomb
- Mechanical Data on VARTM Resin Systems Was Very Limited Except for BMI Materials
  - Typically Had Lower Mechanical Properties And Toughness Than Prepreg Materials
  - Will Require Extensive Certification

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VARTM Evaluation

Scale-up

- Difficult to Lay-up Large Continuous Dry Fabric Shell, Particularly on Vertical or Hanging Surfaces Due to Preform Weight and Lack of Tack
- Need to Validate High Fiber Volumes on Large Structures- Large Structures Demonstrated In Industry Have High Resin Volume (Typically > 50%)
- Stitching / Approaches For Compaction of Preforms to Achieve Higher Fiber Volumes or For Integrating Doublers and Build-ups Limits Size and Increases Need for Joints or Alternative Location/Compaction Methods
- Difficulty in Eliminating Bulk of Dry Preform On Full Cylinder Increases Likelihood of Fiber Waviness in Cured Part
- Difficult to Avoid Mark-off and Resin Rich Areas At Resin Introduction Points
  - Introduce at Part Edges Implies More Joints Due to Size
  - Minimal Joint Designs Imply Very Long Flow Paths or Resin Introduction in the Middle of the Structure
- Environmental and Safety - Very Large Chemical Storage Needs, CRB Approvals, Permits, Resin Mixing Etc

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VARTM Evaluation

Compatibility with Design

- May be Suitable for Monolithic Structure Concepts and for Slosh Baffles
- Use of Fabrics For Full Surface Will Impose ~10% or Higher Weight Penalty
- Significant Weight/Quality Risk, Particularly to Prevent Resin Ingression for Honeycomb Sandwich Design
- Limits Flexibility to Designs Highly Tailored to VARTM Process Limitations (e.g. Preform Geometry Limitations, Injection Process, etc.)

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Enhanced Processing Techniques

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Enhance Cure Processing Approaches

Mandrel Expansion

- Internal Aluminum Mandrel
- External Shell With Silicone Rubber Face

Shrink Tapes/Materials

- ID Select Shrink Tapes
- Use Kevlar Over-wrap
- Silicone Rubber Elastomer, Over-wrap Under Tension

Bagging Techniques

- Double Bagging
- Improved Debulking
  - Increase Frequency
  - Hot Debulks vs. RT Debulks

Specialty Materials

- Net Thickness Prepreg
- Low Pressure Cure Materials

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Enhance Cure Processing Evaluation

Materials Maturity

- Low Pressure Processing Materials (e.g. LTM) Did Not Have Acceptable Mechanical Properties or Had Unacceptable Out Times
- Net Thickness Prepreg Materials Have Only Been Used for Autoclave Cures
- Standard Prepreg Materials Selected for Most Process Testing
  - Will Compare To Mechanical Test Data for Autoclave Cured Materials
  - Minimal Mechanical Data Available for Vacuum Bag Cure

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Enhance Cure Processing Evaluation

Design Compatibility

- Shrink Tape Approach Limited by Contour
  - Must Be Male Tool With Convex Surface
  - Difficult to Apply to Dome/Compound Contour Areas
  - Difficult to Incorporate Localized Features Without Causing Bridging
- Mandrel Expansion
  - Aids IML Skin Compaction, But Questionable for Doublers Features Not Constrained by Skin Plies and Processes After Skin is Cured
  - Tooling Complexity Increases for Outer Skin Compaction
  - Must Rely on Other Complementary Processes
  - Expansion Approach Limits Tool Design Flexibility
- Bagging Techniques and Specialty Materials Appear Compatible With Most Designs Proposed

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Enhance Cure Processing Evaluation

Scale Up

- Materials Must Have Compatible Out-life with Proposed Process Approaches
- Shrink Tape
  - Application Process On Full Scale Tanks May Need Development or Automation Due to Weight of Rolls
- Improved Debulking
  - Need to Ensure Scale-up Does Not Exceed Material Out-life Due to Increased Process Flow Time
- Recommend Automated Material Application for All Concepts Proposed
  - Aids Debulk
  - Reduces Flow Time and Improves Ability to Complete Process Within Out-life of Materials

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Non Autoclave Cure Photomicrographs

All Material A Vacuum Bag Cure Panels Had Unacceptable Disbonds or Porosity

Mat'l A - Panel #1

Mat'l A - Panel #1A

Standard Lay-up, Vacuum Bag Pressure Only Mat'l A Panel # 3

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Non Autoclave Cure Photomicrographs

Standard Debulk/Lay-up, Vacuum Bag Pressure Only Mat'l B Prepreg Panel #2

Standard Debulk/Lay-up, Vacuum Bag Pressure Only, Mat'l B Net Thickness Prepreg Panel # 6

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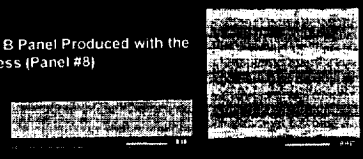
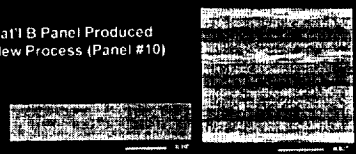
Non Autoclave Cure Photomicrographs

First Mat'l B Panel Produced with the New Process (Panel #8)



Second Mat'l B Panel Produced with the New Process (Panel #10)



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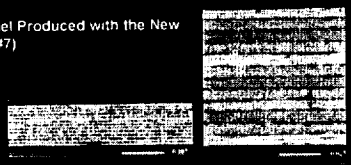
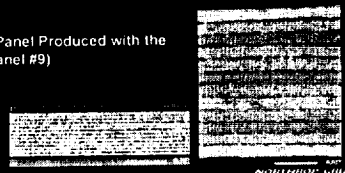
Non Autoclave Cure Photomicrographs

First Mat'l C Panel Produced with the New Process (Panel #7)



Second Mat'l C Panel Produced with the New Process (Panel #9)



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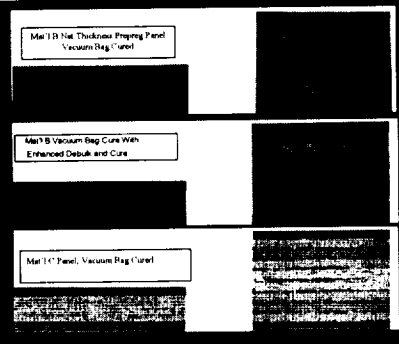
Non Autoclave Cure Photomicrographs

Comparable Results From Panels Made for M&P Testing



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Enhance Cure Panel Processing Summary

Panel	Material	Process	Cure	Thickness	Visual Quality	Comments
1	A	Baseline	Baseline	N/A	Very Poor	Delaminated Ply
1A	A	Baseline	Baseline	N/A	Very Poor	Delaminated Ply
2	B	Baseline	Baseline	0.066	Fair	Surface Porosity
3	A	Baseline	Note 1	N/A	Poor	Very Porous
4	A	Note 2	Note 2	N/A	Poor	Very Porous
5	A	Note 3	Note 3	N/A	Poor	Very Porous
6	B Net	Baseline	Baseline	0.063	Fair	Surface Porosity
7	C	New	New	0.067	Good	Very Porous
8	A	New	New	0.06	Very Good	Good Panel
9	C	New	New	0.068	Good	Very Porous
10	A	New	New	0.06	Very Good	Good Panel
11	A	New	New	Core Panel	Very Good	Good Panel

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Ultrasonic Compaction With Vacuum Bag Cure

Collaborative Effort Between Northrop Grumman and Foster Miller

(Utilizes Foster Miller Patented Technology)

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Ultrasonic Compaction Evaluation

Materials Maturity

- Materials Selected Are Production Proven Prepreg Materials
- Ultrasonic Compaction Properties Did Not Degrade Laminate Quality when used with Autoclave Cure on Other Programs
- Minimal Properties Available for Non-autoclave UTL Processing, Equivalency Testing Required to Compare to Autoclave Properties
- Not Previously Demonstrated to Over Core

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Ultrasonic Compaction Evaluation

Scale Up

- Requires Automation
  - Should be Integrated with Automated Tow or Tape Lamination Equipment for Large Cryotank Structures
  - Needs Evaluation/Development to Determine if Lamination and Compaction Should be Performed Simultaneously or Independent of Each Other for Optimal Lamination Speeds
- Development Underway to Scale to Larger Width Compaction Heads
- Needs Demonstration on Compound Geometry with Wider Width Heads
- May Require Special Horn Configurations for Complex Details Such As Hats

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Ultrasonic Compaction Evaluation

- Design Compatibility
- Compatible with All Designs that Could be Tow / Tape Placed
- More Difficult to Support Complex Details Like Hats
- Solid State Cure Process Needs Validation for Each Material System
  - Not Compatible with All Composite Materials
  - May Pose Challenge with Some Adhesive/Material Combinations to Get Proper Adhesive Flow

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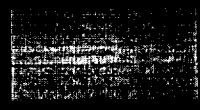
Ultrasonic Compaction Photomicrographs

UTL/Vacuum Bag Oven Cure
WR1123A LH2 Panel Mat'l A

UTL Shows Significant Compaction Improvement Compared to Conventional Vacuum Bag Cures With Mat'l A And Approaches Quality of Autoclave Cure



Conventional Autoclave Cure
ASDL159805 LH2 Panel Mat'l A

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Ultrasonic Compaction Photomicrographs

UTL With Vacuum Bag Cure, and with Solid State Cure Had Near Autoclave Compaction Quality with Mat'l B. Needs Further Development for Thicker Laminates and Other Resin Systems

Vacuum Bag Oven Cure
WR1129 LH2 Panel Mat'l B

Solid State Cure (No Vacuum Bag Oven Cure)
WR1120 LH2 Panel Mat'l B

Conventional Autoclave Cure
ASDL15771 LOX Panel Mat'l B

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Ultrasonic Compaction of Laminates

- Initial H/C Panels
  - Free Standing Solid State Cure (SSC)
  - No UTL Induced Pillowing
  - Good Adhesive Fillets
  - Laminate Quality Will Improve with Vacuum
  - Future Trials Expected Improve Quality of SSC Over Core

Mat'l B Laminate Photomicrograph
- Solid State Cure
- Minimum Voids
- Ply Thickness Within Specified Thickness

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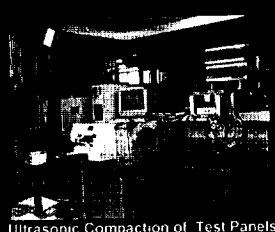
Mechanical Test Panel Fabrication

- UTL Processed and Standard Oven Cure (Material B)
  - Average Per Ply Thickness 0.0051-0.0052"
- UTL Processed and Solid State Oven Cure (Material B)
  - Excellent Quality
  - Limited Flow
  - 0.0052" Average Per Ply
- C-scan Performed at West Penn NDT, Inc



Ultrasonic Compaction of Test Panels

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Sample of UTL Processing Parameters

Panel #	Material	Detailed Process Data
1125		
1129		
1134		
1140		

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Non-Autoclave Process Candidates

Qualitative Comparison

Criteria	Ultrasonic Compaction		Enhanced Thermal Processing						VARTM
	Mat'l B	Mat'l A	Mandrel Expansion	Bagging Techniques		Shrink Tapes /Materials	Specialty Materials		
			IML	OML	Mat'l B	Mat'l A, Mat'l C	Low Press	Net Thick	
Compatibility With Design	●		◐		○		○		
Ability To Be Scaled Up	●				○	●	○		
Maturity of Materials	●		◐		○	◐	○		
Laminate Quality	●		?		◐	?	?	?	

● Green ● Yellow ● Red

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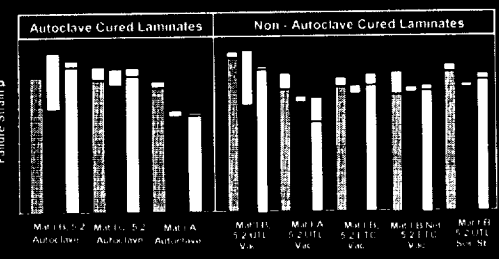
Mechanical Property Test Results

Open Hole Tension Strain



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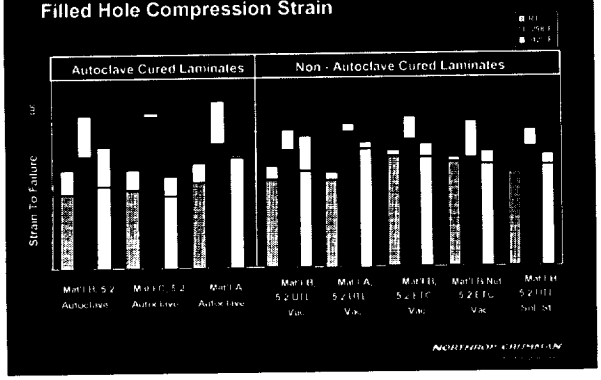
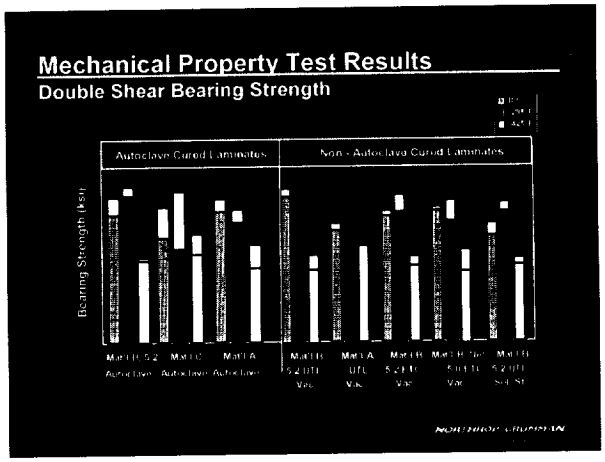
Mechanical Property Test Results

Filled Hole Compression Strain



Mechanical Property Test Results

Double Shear Bearing Strength



Processing Scale-up

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Non-Autoclave Process Scale-Up

Issue

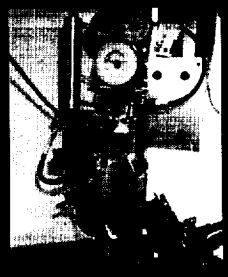
- 2nd Gen RLV Cryotank Sizes Up to 27.5 Feet Diameter and 83 Feet Long*
- Current National Autoclave Capability Is Limited to 25' Diameter (22' Maximum Tank OML)
- Segmented Tanks Require Joints That Pose Leakage Issues and Significantly Increase Complexity of Design, Manufacturing, and Maintenance

Approach

- Scale Up Existing Non-Autoclave Processes for Cryotank Manufacturing Operations

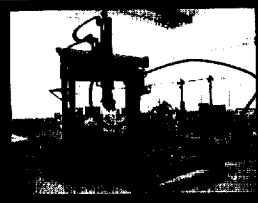
*Saturn V = 33', Shuttle ET = 27.5'

Foster Miller Development UTL Head



Close up the Foster Miller UTL Head

Gantry Machine Modifications



NGC Gantry Being Modified

- Foster Miller Ultrasonic Head In Work
- Capital Asset PO for AIM in Process
- Gantry / Ultrasonic Head Integration Complete by End of Basic Period
- Equipment to Be Used for Panel and Full Scale Element Fabrication in Option 1

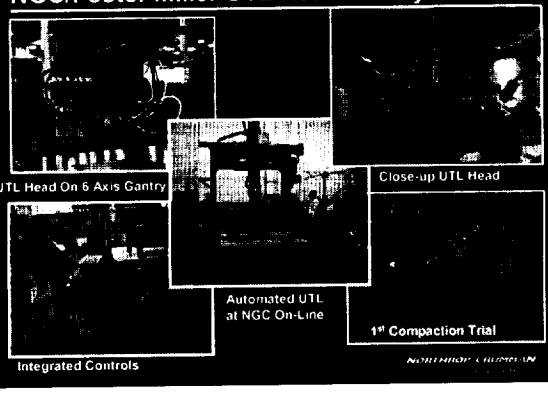
6th Axis

Foster Miller Developed Ultrasonic Head

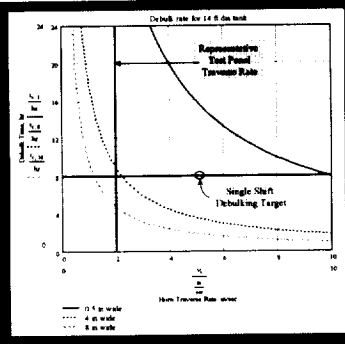
Mounting Ultrasonic Head on Gantry

- SOW Generated for AIM
  - Add 6th Axis with Head Interface Plate
  - Integrate UTL Control Functions
  - Install and Route Cabling, Power and Pneumatic Systems for Head

NGC/Foster Miller UTL Head/Gantry



Effect of Debulking Pass Width and Horn Traverse Rate on Debulk Time



Ultrasonic Head Development for Full Scale Applications

- Evaluation of Secondary or In-situ Detailing
- Evaluation of Compaction Time vs Horn Width
- Evaluation of Conventional vs Smaller Multi-Horn Systems
  - Conventional off the Shelf Ultrasonics
    - Proven Through Years of Industrial Use
    - Bulky, Heavy Multiple Horn System
    - Limited Contact Region
  - Newly Prototyped Miniature System
    - Streamlined Multiple Horn System
    - Requires Additional Operational Testing

Concept Multi Horn System

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Subscale Development

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Subscale Tank Manufacturing

Issue

- All Up Tank Test Including LH2 Pressure Cycling and Axial Loads Required Before Option II to Achieve TRL of 6 by 2005
- Non-Autoclave Processing Development Schedule May Not Support Option I Tank Fabrication

Approach

- Fabricate and Test Autoclave Cured Subscale Tank in Option I to Validate Structural Design and Cryogenic Performance
- Make Subscale Tank Details Representative of Full Scale Designs to the Maximum Extent Possible

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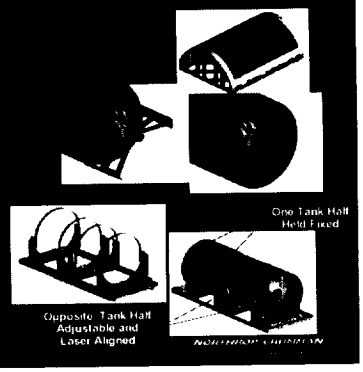
Subscale Tank Tooling Status

- R3614167105 Skirt Skin Cure Fixture
- R3614167107 Skirt Skin Bond Fixture
- R3614167111 Assembly Bond Fixture



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Subscale Tank Risk Mitigation Activities

- Perform Tooling Coordination and Interface Check with Existing NASA Tools (Designs In Work)
- Evaluating Protocol Established for Working On Site At NASA
- Coordinating NGC Support and Personnel Required to Work On Site At NASA- Mfg Eng., Technicians, Quality, and Engineering Manufacturing Process Risk Reduction Activities Started
- Overall Procedures / Work Process Dry Runs Started Using Process and Tool Proof Articles Prior to Fabrication of Subscale Tank In Option 1

Resolving Natural Path Issues and Improved Lamination Techniques Eliminated Wrinkles

Dome Wrinkles 1st Attempt

2nd Trial Without Wrinkles

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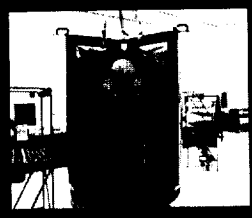
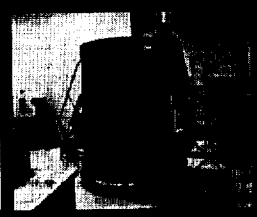
Subscale Tank Development Activities



Subscale Tank Wall with Core



Placing Tank OML Skins

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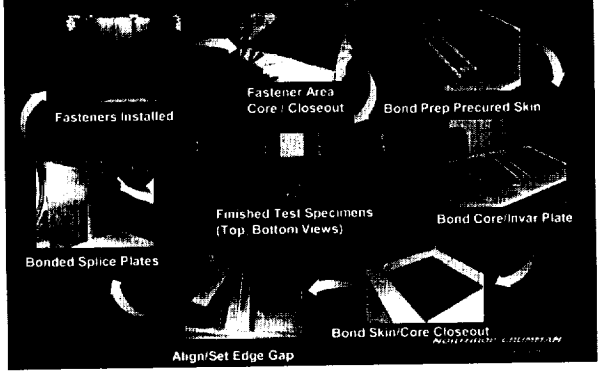
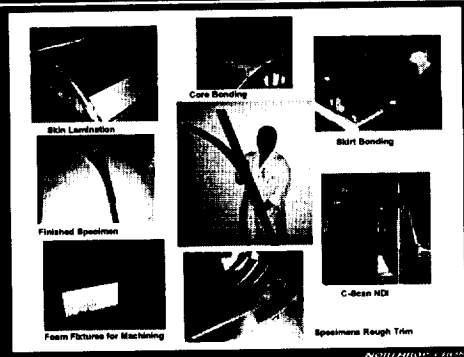
Belly Band Producibility Panel



Y-Joint Test Specimen Fabrication



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Summary of Accomplishments

Manufacturing

- Non-Autoclave Process Trials Complete
- Head Fabrication and Gantry Modifications 100% Complete
- Subscale Tank Test Element Fabrication Complete
- Subscale Tank Composite Splice Plates Complete
- Subscale Tank Tools 100% Complete
- Subscale Tank Risk Mitigation Demo Complete
- Full Scale Tank Simulation Models Complete
- Conceptual Seamless Tank Tool Designs Complete

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